The Threat of Financial Contagion is Real: Analyzing Shock and Volatility Spillovers from the Global Crisis*

Introduction

While a double-track global economic growth pattern persists—where growth in advanced economies slows and emerging markets continue their rapid expansion—recent data clearly show emerging East Asia has started to decelerate.[7] Weakening external demand has hit many export-oriented economies. Corporate profits are down, industrial growth is declining or even contracting in some economies, and stock market values are drifting downward. However, in the midst of this gradual deceleration, bond markets have been resilient—with issuance and the value of bonds outstanding up, and yields down.

Emerging East Asia's bond markets grew by 8.6% y-o-y in 2Q12 to US$5.9 trillion. More encouragingly, corporate bond growth continues to outpace that of government bonds—where markets are more developed. The global share of emerging Asia's local currency (LCY) bond markets continues to increase, and is now higher than in Latin America and the eurozone **(Table 11)**. This removes the possibility of currency mismatches, like those present at the onset of the 1997/98 Asian financial crisis. It also helps reduce the region's overreliance on banks for finance. In addition, it allows authorities to better use macroeconomic measures and monetary policy as effective countercyclical tools during global financial crises.

But is this a "new normal"? Is the trend cyclical or structural? While not easy to answer, one thing is clear—market uncertainty dominates. With the eurozone still unsettled, the United States' (US) "fiscal cliff" approaching, a potential food crisis looming, and growth in emerging markets—including the People's Republic of China (PRC)—slowing, risks and uncertainties mount. Indeed, financial market volatility has been high, both during the Lehman shock in 2008/09 and the current eurozone debt crisis.

The focus of this chapter is to examine the nature and intensity of the spillover effects of the global

Table 11: Currency Denomination in Bond Markets by Broad Area (%)

	2000		2005		2010		2011[a]	
	LCY	FCY	LCY	FCY	LCY	FCY	LCY	FCY
eurozone	90.0	10.0	89.9	10.1	89.8	10.2	90.3	90.7
Japan	98.5	1.5	91.1	0.9	99.4	0.6	99.4	0.6
Latin America	46.0	54.0	59.9	40.1	71.2	28.8	70.8	29.2
Emerging Asia[b]	88.4	11.6	91.2	8.8	94.2	5.8	94.3	5.7

FCY = foreign currency, LCY = local currency.
[a] as of end-September 2011.
[b] Emerging Asia includes India, Indonesia, the Republic of Korea, Malaysia, and the Philippines.
Source: P. Turner. 2012. Weathering Financial Crisis: Domestic Bond Markets in EMEs. *BIS Papers*. No. 63. Geneva: Bank for International Settlements.

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[7] Emerging East Asia comprises the People's Republic of China, Indonesia, the Republic of Korea, Malaysia, the Philippines, and Thailand.

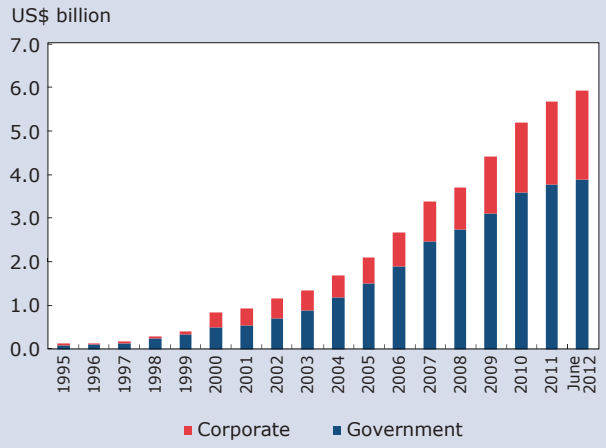
financial crisis on LCY debt markets in emerging East Asia. It is shown that, while debt markets are becoming more robust, volatility is on the rise. Deepening debt markets—especially corporate bonds—provide alternative financing with minimum risk of currency or maturity mismatches. Yet, in some countries the shock and volatility spillovers from the global financial crisis are significant, real, and need to be addressed before they create new vulnerabilities and exacerbate the ongoing economic slowdown.

The first section examines the impact of the crisis on LCY bond market growth. The second looks at the impact on returns, yields, and market volatility, with several policy measures highlighted. In both sections, the analysis is descriptive. A more detailed analysis using quantitative models is conducted in section three.

Crisis and the Growth of Bond Markets

LCY bond markets in emerging East Asia have grown at an annual average rate of 16.5% over the past 10 years. By 2011, they reached US$5.7 trillion **(Figure 14)** and accounted for 8.4% of the global market, up from 2.1% in 1996.[8] This is encouraging as LCY bond markets are a key source of funding for both governments and domestic companies. Local banks also turned to local bond markets to strengthen their capital base with subordinated debt.

Figure 14: Growth of the Emerging East Asian LCY Bond Market



LCY = local currency.
Note: Emerging East Asia comprises the People's Republic of China; Hong Kong, China; Indonesia; the Republic of Korea; Malaysia; the Philippines; Singapore; Thailand; and Viet Nam.
Source: *AsianBondsOnline*.

Deposit institutions have long been the primary source of capital in Asia, leaving the region's financial system skewed toward banks. With expanding bond markets and their growing "spare tire" role, however, the region is gradually making the transition to a more direct financing model, reducing overreliance on bank credit. Also interesting is that corporate bond issuance has outpaced new equity offerings, despite the fact that debt sales in local markets comprise only roughly one-third of total bank lending.

Markets expanded sharply during the first half of 2009 following a significant decline in the fourth quarter of 2008. Issuance in LCY bond markets by both governments and companies surged in the wake of the Lehman collapse in September 2008. This coincided with rising capital inflows as the region's financial markets were considered a safe haven by investors. Increased government issuance supported massive official stimulus programs to pump prime economies affected by the global financial crisis.

But more important has been the continued strong growth of corporate bonds. From the perspective of both issuers and investors, bonds are attractive. Issuers take advantage of coupon rates being below bank lending rates, while investors see the asset class as a safe heaven. This has occurred despite slowing economic growth and investment demand in general, and widening corporate bond spreads in the wake of the global financial crisis. The timing and factors behind this trend reflect a structural shift in local bond market development.

During the crisis, large companies tapped local bond markets to raise funds as banks turned cautious and became reluctant to lend as funding

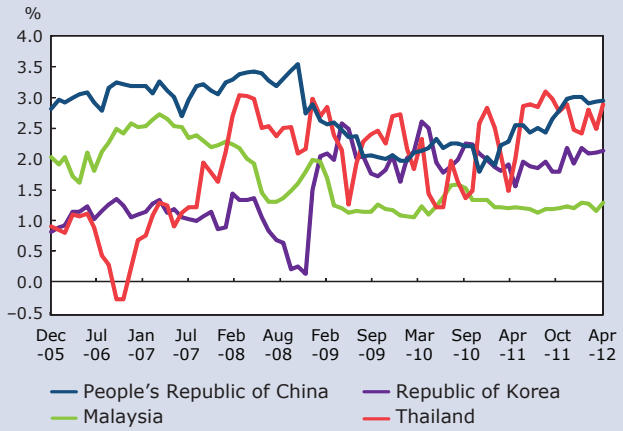
[8] Emerging Markets Bond Index (EMBI) Global gained 7.2% in 2011, making this segment the best performing asset class in the fixed-income market worldwide.

conditions in global markets tightened. While large companies substituted bank loans by raising funds through bond markets, local market borrowing costs also tilted the scale in favor of bond markets. Even though corporate bond spreads widened, they remained below prime lending rates in many markets **(Figure 15)**. This allowed many firms to continue raising funds for new projects, refinance maturing liabilities, and even pre-fund some borrowing requirements.

Rising capital flows reinforced the trend. Seeking shelter from the turmoil in industrial countries, investors piled into emerging market debt, pushing yields down further. Emerging East Asian markets are now enjoying developed market borrowing costs. They are evolving from return-enhancers to buffer-providers against volatile markets.[9]

The question is how much volatility can these markets handle before falling prey to a downward trend, as is happening with equity markets? Flows into local bond markets have increased partly because investors are seeking to both diversify their portfolios away from longstanding home biases, as well as take advantage of the strong emerging market economic fundamentals. But market reactions globally have increasingly been less correlated with fundamentals. More and more, market sentiment is influenced by factors outside macroeconomic fundamentals, making policy measures less effective.

Figure 15: Spread Between Prime Lending Rate and Corporate Bond Yield



Source: Bloomberg LP, EDAILY *BondWeb*, Bank Negara Malaysia, International Monetary Fund, and ThaiBMA.

Shocks emanating from the Lehman collapse and the eurozone crisis led yields across local Asian markets to spike, as market sentiment worsened and foreign funds withdrew. These "shock spillovers" also caused liquidity to contract and collateral asset values in many markets to fall. With uncertain conditions in industrial countries continuing—and yields at historical lows—capital flows again increased to emerging East Asia, where returns are higher. The resulting fluctuations ("volatility spillovers") complicate investor decisions and affect market sentiment. This can reduce the effectiveness of policy measures. If this situation is prolonged, the region's economies will be vulnerable to potential new shocks. For many export-oriented East Asian countries, where growth has already been depressed by falling external demand, this can pose a serious problem.

While the impact of shock and volatility spillovers to LCY bond markets may be evident from the volume side, what happens to yields?

Crisis and Yield Trends

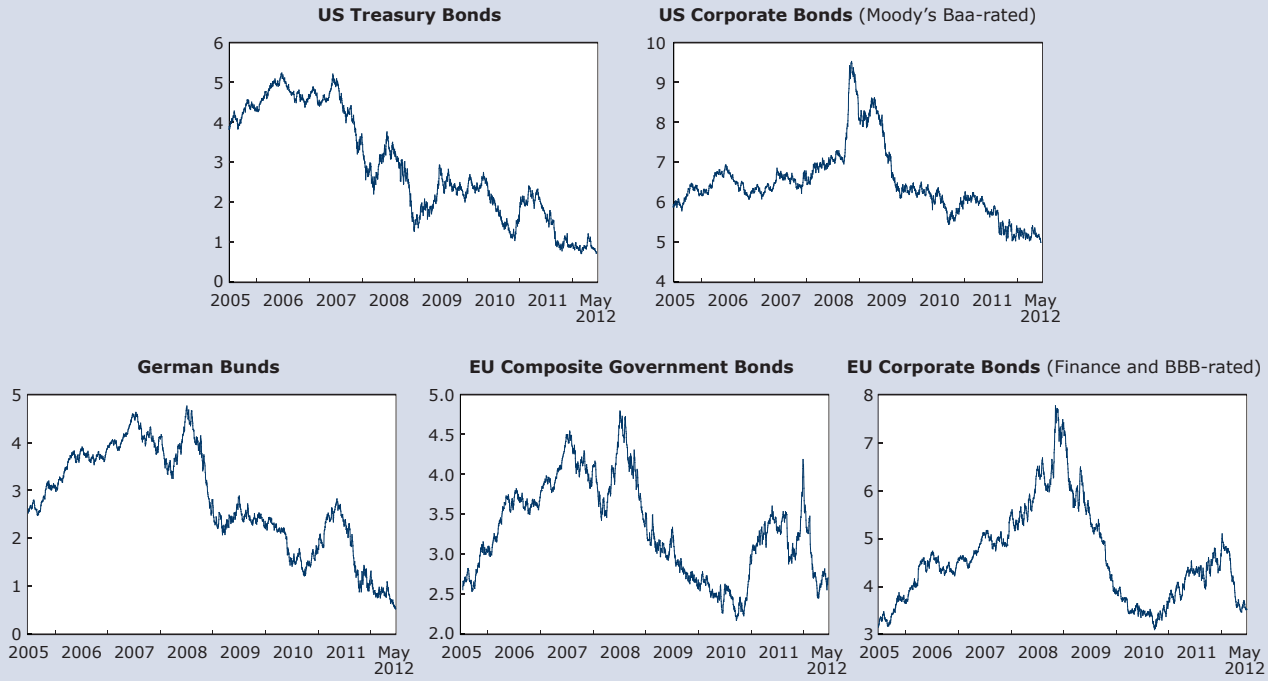
To describe yield dynamics during the global financial crisis, the trend of 5-year benchmark government bond yields of selected Asian markets is compared with the trend of US Treasuries, German Bunds, and US high-yield corporate bonds with similar maturities.[10]

It is clear that global market turmoil following the Lehman shock in September 2008 rattled both mature and emerging market economies **(Figure 16a)**. US and European Union (EU) high-yield corporate bonds saw substantial jumps in yields during the period. The subsequent recovery was then followed by another yield spike for EU high-yield corporate bonds when the Greek crisis reached a new peak in September 2011.

[9] An interesting implication of this is the rise of exotic higher-yield bond markets.

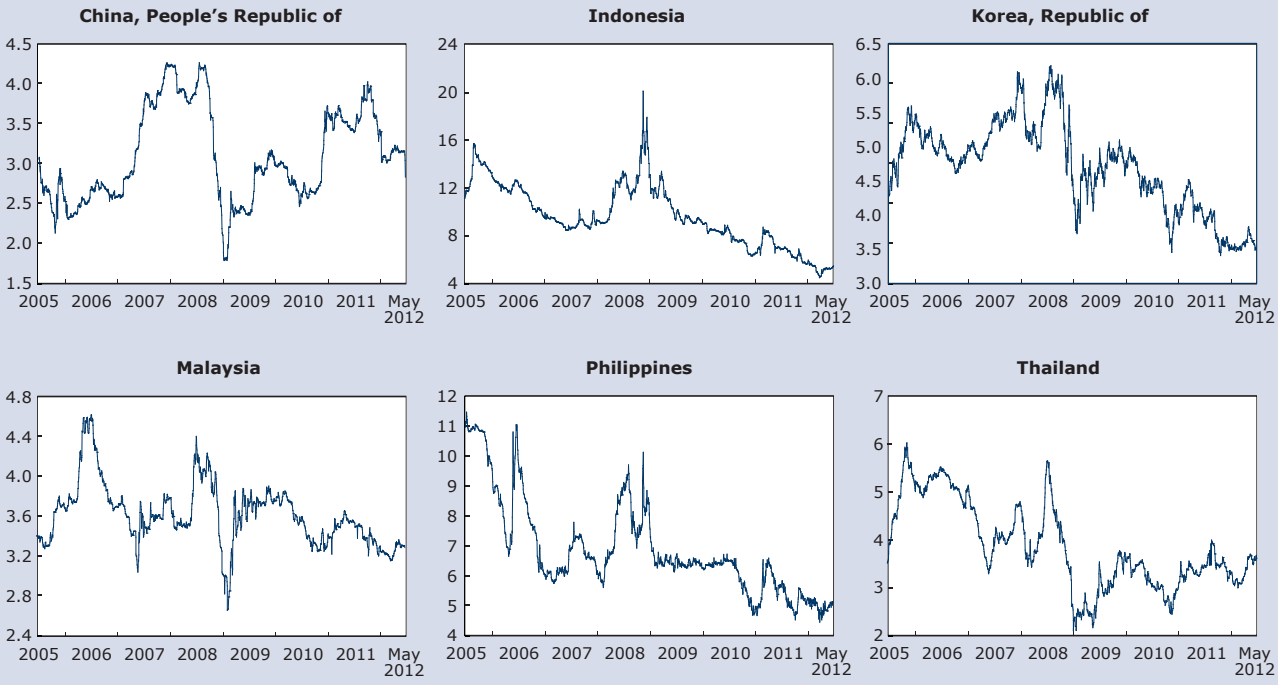
[10] With liquidity in local markets higher in the belly of the curve—usually around the 3 to 7 year bracket—5-year bonds for Asian debt are used.

Figure 16a: 5-Year Benchmark Government Bond Yields—EU, Germany, and the US



EU = European Union, US = United States.
Source: Bloomberg LP.

Figure 16b: 5-Year Benchmark Government Bond Yields of Selected Asian Countries



Source: Bloomberg LP.

Contagion from these two shocks spread to the bond markets of emerging East Asia. During the 2008/09 Lehman crisis, government bond yields in the Republic of Korea, Malaysia, and Thailand increased by as much as 2 percentage points, while those in Indonesia rose as much as 9 percentage points and the Philippines by 4 percentage points. **(Figure 16b)**. Indonesian and Philippine benchmarks somewhat followed yield trends of US high-yield corporates—with Indonesia's being slightly higher—suggesting a comparable asset categorization.

During the Lehman shock in September, Indonesia's rupiah bond market was the worst hit in the region—as the entire yield curve shifted upward—with rates ranging between 11.3% and 13.6% from the short- to the long-end of the curve. Fears of a sharp economic slowdown, together with rising domestic inflation and abrupt withdrawals of foreign funds, drove down bond prices and led to a sudden evaporation of market liquidity. As market conditions became very volatile during the last quarter of 2008, authorities cancelled all scheduled local debt auctions.

Yields on government bonds in the Republic of Korea shot up amid a liquidity shortage in local financial markets—exacerbated by an increase in risk aversion by foreign investors. Authorities responded aggressively by implementing stimulus packages; slashing base rates; and improving liquidity by reducing issuance of central bank bonds, utilizing currency swap agreements and reverse purchases, and boosting the Bank Recapitalization Fund to improve bank capital.

In the PRC, the government bond yield curve also shifted upward after the September 2008 shock, with rates at the short-end jumping more than 2 percentage points. However, a massive stimulus package, a slew of rate cuts, lowered reserve requirements, and falling consumer price inflation during February–March 2009 led the yield curve to shift back below its pre-September 2008 level.

Thus, authorities across the region generally employed an array of both conventional and unconventional policies to revive growth and stabilize capital markets—helping shield them from the shocks emerging from international financial markets during the 2008/09 crisis. Massive fiscal stimulus aimed at boosting domestic demand and investment, monetary easing and measures to facilitate short-term liquidity, and curbs on speculative activities in foreign exchange markets were some of the measures used to stabilize economies and secure investor confidence.

It is important to note that fiscal stimulus in most countries did not undermine fiscal sustainability—neither did stimulus finance raise major issues for policymakers. Liquidity remained abundant in most regional bond markets—where continued strong appetite for debt from local investors substituted for reduced foreign demand. Where domestic yield curves steepened sharply and long-term liquidity dried up, some judicious shortening of debt maturities helped raise the financing needed for stimulus policies while not adding substantially to rollover and interest rate risk. Government debt managers did deviate from their stated objectives, but continued their practice of publishing issuance calendars with large amounts of long-term tenors. The Philippines and Malaysia also eased mark-to-market rules on banks and financial institutions—major holders of government securities—following the relaxation of the rules by the International Accounting Standards Board (IASB) and other standard setters for illiquid assets.

The Philippine central bank responded to the crisis-related shock with regulatory forbearance. It allowed financial institutions to reclassify investments in debt and equity securities from "held for trading" or "available for sale" categories to "held to maturity" or "unquoted debt securities classified as loans."[11]

The combination of orthodox and unorthodox policies was credible in large part due to earlier policy frameworks—on regulation, debt issuance, and currency flexibility, among others—making

[11] D. Guinigundo. 2012. The impact of the global financial crisis on the Philippine financial system – an assessment. *BIS Paper.* No 54. Geneva: Bank for International Settlements.

balance sheets less vulnerable to market price shocks. Also, domestic markets remained confident that these exceptional measures were merely temporary.[12] To some degree, this lessened the upward pressure on longer-term yields as national authorities made clear that fiscal stimulus would be withdrawn as circumstances allowed. This also helped contain the yield fluctuations, or volatility spillovers, of the eight markets analyzed; only the PRC registers a significant coefficient.

The impact of the eurozone crisis, however, is a rather different story. As the debt crisis in Europe mounted, Asian benchmark yields approximated their pre-September 2008 levels. The severe stress and consequent recovery from the 2008/09 crisis—plus the steady growth of local bond markets since—ignited the debate over whether emerging East Asian markets are truly resilient.

The yield upticks in markets like Indonesia and the Republic of Korea have been attributed to the sudden outflow of foreign funds, reluctance of domestic institutional investors to step in to bridge the liquidity gap, and changes in market sentiment due to turmoil in global financial markets.[13] More importantly, however, volatility has returned as well. Apart from the volatility of cross-border capital flows and increased deleveraging by European financial institutions, central banks and debt management authorities largely view the impact of the eurozone debt crisis as being transmitted through heightened uncertainty and financial market volatility.[14]

This financial market contagion also hit the PRC, where the bond market was hurt by fears of a sharper-than-expected growth slowdown and rising market uncertainty. As a result, yields rose nearly 40 basis points at the short-end of the curve from end-July through end-August 2012.

Thus, the spillovers from the global financial crisis in terms of shock and volatility in emerging East Asia's bond yields are evident. The extent of these spillovers, however, remains unexplored. While one can visually compare the yield movements during the two crises, volatility clustering and leverage effects commonly observed in high-frequency financial data can distort the conclusion. Moreover, the significance of movements caused by spillovers from the crisis and those caused by the persistence of own-shocks is still unknown. Yet, policy measures to address the problems may be different. The distinction between "shock spillovers" and "volatility spillovers" also needs to be made.

Shock and Volatility Spillovers and Own-Market Persistence

In examining the spillover effects of a shock in one market on another, GARCH models have been used extensively.[15] For our purpose, the first step is to use a univariate GARCH to extract conditional variances of the shock sources (yields of 5-year US Treasuries, German Bunds, US and EU high-yield corporate bonds) and of the impacted markets (yields of LCY government bonds in eight East Asian countries).

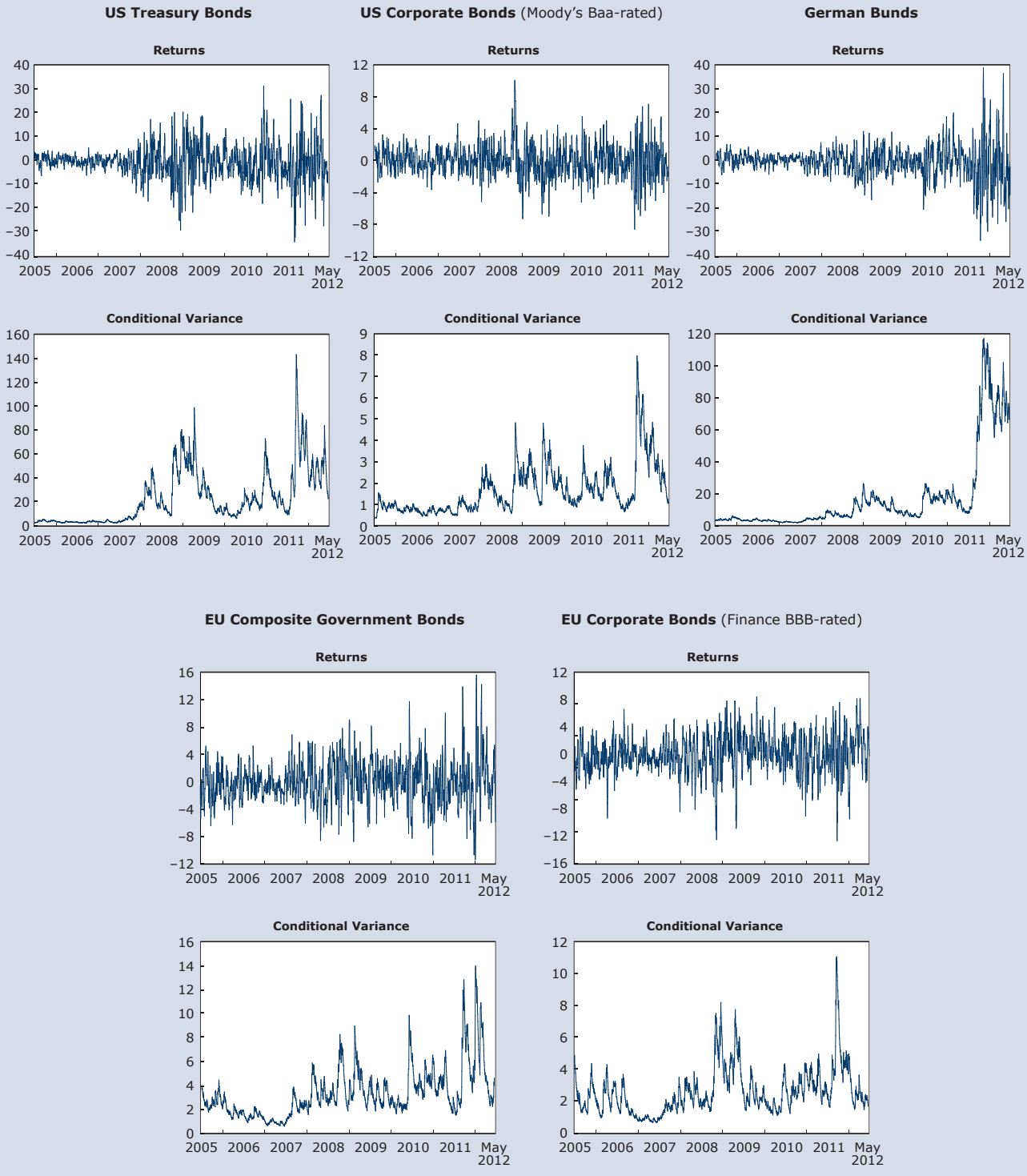
It is clear that yields on 5-year US Treasuries and German Bunds were affected by the Lehman shock in 2008 **(Figures 17a, 17b)**. The volatility spike for German Bunds was smaller compared with that for US Treasuries. Together with the observed downward trends, the heightened variability of yield returns for these two markets imply a "flight to safety and liquidity" by investors. The huge financial market stress drove down investor sentiment, making most, if not all, investors take refuge in less risky government securities in the US and Germany. In the meantime, the volatilities of US and EU high-yield corporate bond returns began to rise.

In the run-up to the eurozone sovereign debt crisis, volatility spiked again. The region's

[12] P. Turner. 2012. Weathering Financial Crisis: Domestic Bond Markets in EMEs. *BIS Paper*. No. 63. Geneva: Bank for International Settlements.
[13] Yields of government bonds in Indonesia, Malaysia, and Thailand began to edge up in July and August 2012 on renewed uncertainty—despite the continued decline in US and German bond yields.
[14] Bank Negara Malaysia. 2012. *Annual Report 2011*.Kuala Lumpur.

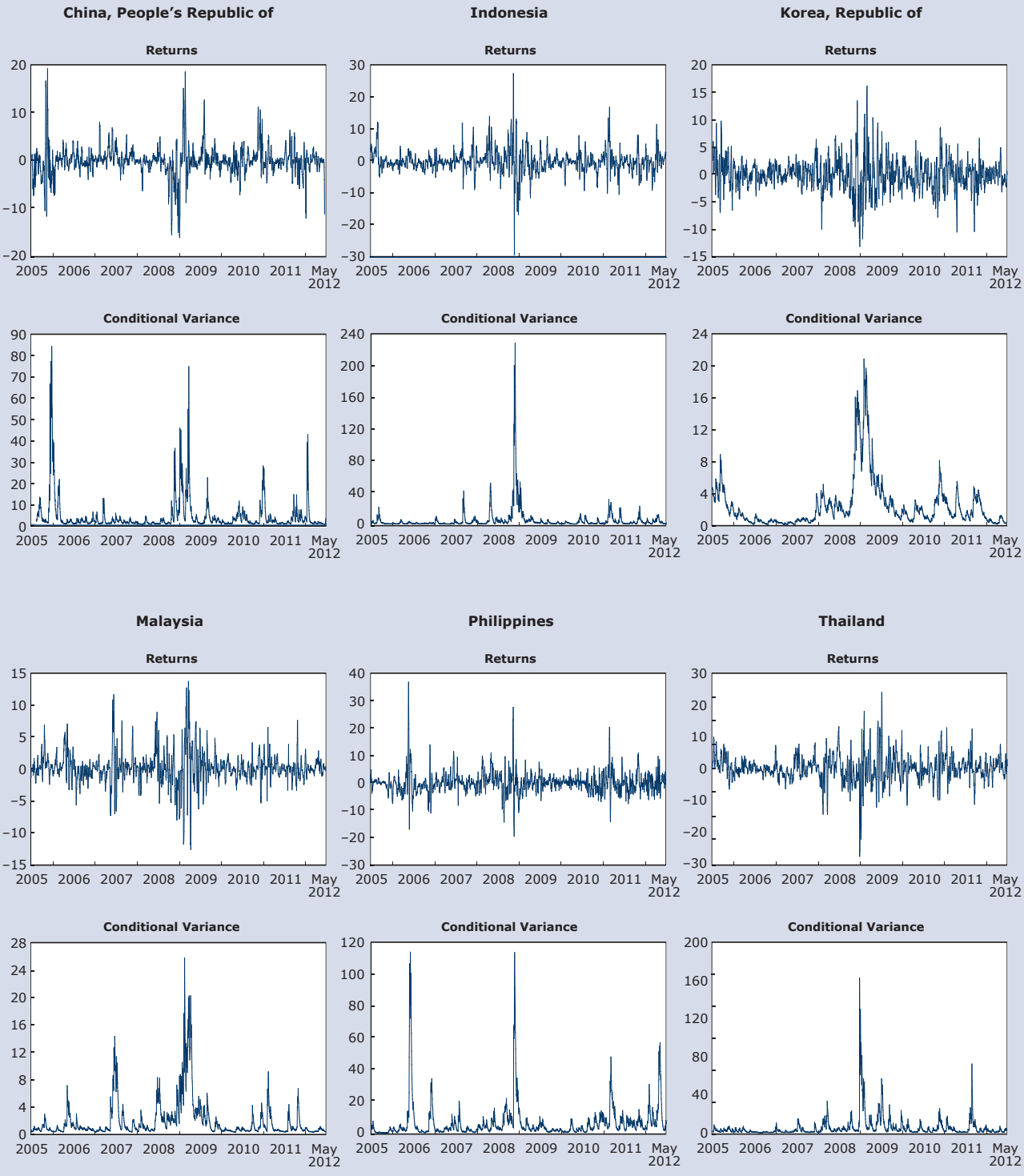
[15] GARCH refers to generalized autoregressive conditional heteroscedasticity. Variances of the returns obtained from the mean equation are modeled as a GARCH process to generate the conditional variances (preferred than unconditional variances because of volatility clustering issue and leverage effect problem in high frequency data). More detailed explanations are in the Appendix to this chapter.

Figure 17a: Volatility Patterns of Government Bonds and Corporate—EU, Germany, and the US



EU = European Union, US = United States.
Source: ADB's Office of Regional Economic Integration calculations.

Figure 17b: Volatility Patterns of Government Bonds of Selected Asian Countries



Source: ADB's Office of Regional Economic Integration calculations.

fiscal woes only intensified financial market uncertainty, resulting in prolonged and wider yield return variability. The EU composite bond shows a different volatility pattern—the spikes observed during the eurozone debt crisis are more prominent for the composite than for German Bunds. Considering that the EU composite contains all rated sovereigns from the eurozone, the higher volatilities reflect the large risk premium investors attach to Portugal, Ireland, Italy, and Spain. These heightened fluctuations spiked substantially in September 2011.

How did these two markets affect Asia? Markets in selected countries showed marked spikes in volatility during the Lehman collapse and the eurozone sovereign debt crisis. Volatilities in yield returns may not have been as sharp or persistent as compared with those of the shock sources (US Treasuries, German Bunds, and US and EU corporate securities). Nonetheless, it is clear that there remains underlying yield volatility in Asian markets despite yields leveling off since the end of 2008.

But how do we know if the above trends are due to spillovers or own-market persistence? Are the spillovers significant in terms of shock and volatility? By running bivariate GARCH models using daily data on returns (subsequently converted to week-to-week) extracted from Bloomberg covering the period of June 2005 to May 2012, it becomes clear that—while Asian government bond returns and volatilities are more determined by the dynamics of own markets—contagion effects from the Lehman and eurozone crises remain significant in some countries. The shock spillovers from the Lehman collapse affected five Asian markets—the PRC, Thailand, Malaysia, the Republic of Korea, and the Philippines; the spillovers from the eurozone crisis affected three markets—the PRC, Thailand, and Indonesia **(Tables 12, 13)**. The strongest shock spillover during the eurozone crisis has been in the PRC. In fact, the region's shock spillover coefficients are generally higher during the 2008/09 crisis than during the eurozone crisis, except for the PRC.

Judging from the magnitude of coefficients, during the 2008/09 crisis the most significant shock spillovers came from the US high-yield corporate bond market. The most affected markets were those of the Republic of Korea, Malaysia, and the Philippines (coefficients averaging 0.3). Similarly, there were shock spillovers from EU high-yield corporates to the PRC and Thailand, and from EU composite bonds to the PRC. In terms of volatility spillovers, US corporate bond movements affected the PRC market significantly in the 2008/09 crisis, whereas during the eurozone crisis EU corporate (financial) bonds significantly affected markets in the Philippines (the coefficient is close to 2.0) and Thailand (0.4).

This highlights the uncertainty over the transmission of spillovers from the eurozone debt crisis and its impact on Asia's LCY bond markets. This is why Asian authorities should be aware and prepared for any possible disruptive spillovers.

Shock and volatility persistence of own markets is generally similar during the two crises. The own-shock persistence in Thailand and the Philippines was stronger in 2008/09 (Thailand has the highest coefficient) than in 2011. In Indonesia, the Republic of Korea, and Malaysia, the effect of the eurozone crisis was stronger (Indonesia has the highest coefficient). In terms of own-volatility persistence, during the two crises the results of all countries are significant, but EU corporate bonds appear to transmit significant volatility persistence only in the Republic of Korea, Malaysia, Indonesia, and the PRC.

These results clearly show that prior-period shocks and volatilities have manifested themselves on own-market performance.[16] The persistence of prior-period volatilities are more distinct than the prior-period shock—with values for own-shock coefficients averaging 0.2 while those for own-volatility average 0.8, suggesting that market perception about return fluctuations is more pronounced during bouts of financial market stress.

[16] Unlike in the preceding section, however, here the volatility clusters that tend to appear during a crisis are taken into account (reflected in the larger coefficient).

Table 12: Shock and Volatility Spillover (coefficients significant at 5% level)

Source Market or Country	Shock Spillover				Volatility Spillover			
	Lehman Collapse		EU Debt Crisis		Lehman Collapse		EU Debt Crisis	
	Asian Market	Coefficient	Asian Market	Coefficient	Asian Market	Coefficient	Asian Market	Coefficient
US Treasury Bonds	Thailand	0.0423						
	PRC	0.0210						
	Malaysia	0.0114						
US High-Yield Corporate Bonds	Malaysia	0.4867			PRC	0.8546		
	KOR	0.3875						
	Philippines	0.2021						
German Bunds			PRC	0.0068				
			Thailand	0.0019				
			Indonesia	0.0014				
EU Composite Government Bonds			PRC	0.1081				
EU High-Yield Corporate Bonds			PRC	0.0956			Philippines	1.9797
			Thailand	0.0426			Thailand	0.3600

EU = European Union, KOR = Republic of Korea, PRC = People's Republic of China, US = United States.
Source: ADB's Office of Regional Economic Integration.

Table 13: Shock and Volatility Persistence (coefficients significant at 5% level)

Source Market or Country	Own-Shock Persistence				Own-Volatility Persistence			
	Lehman Collapse		EU Debt Crisis		Lehman Collapse		EU Debt Crisis	
	Asian Market	Coefficient	Asian Market	Coefficient	Asian Market	Coefficient	Asian Market	Coefficient
US Treasury Bonds	Indonesia	0.1957			Malaysia	0.8629		
	Thailand	0.1346			KOR	0.8562		
	KOR	0.0832			Philippines	0.8101		
	PRC	0.0729			Indonesia	0.8033		
	Philippines	0.0687			PRC	0.8007		
	Malaysia	0.0451			Thailand	0.7332		
US High-Yield Corporate Bonds	Thailand	0.3969			Indonesia	0.8464		
	PRC	0.1352			Philippines	0.8207		
	Indonesia	0.1343			KOR	0.7942		
	Philippines	0.1198			Thailand	0.6674		
	Malaysia	0.0580			Malaysia	0.6556		
	KOR	0.0480			PRC	0.5574		
German Bunds			Indonesia	0.2977			Philippines	0.9149
			Malaysia	0.2036			KOR	0.8704
			PRC	0.1058			Malaysia	0.7382
			Thailand	0.0989			Indonesia	0.7098
			Philippines	0.0818			PRC	0.6917
			KOR	0.0595			Thailand	0.6368
EU Composite Government Bonds			Indonesia	0.1790			KOR	0.8740
			Malaysia	0.1402			Indonesia	0.8093
			Philippines	0.1149			Philippines	0.7361
			KOR	0.0763			Malaysia	0.6953
			Thailand	0.0671			PRC	0.6947
							Thailand	0.6538
EU High-Yield Corporate Bonds			PRC	0.2155			KOR	0.8649
			Indonesia	0.2010			Malaysia	0.7918
			Malaysia	0.1535			Indonesia	0.7606
			Philippines	0.0653			PRC	0.6928
			KOR	0.0469				

EU = European Union, KOR = Republic of Korea, PRC = People's Republic of China, US = United States.
Source: ADB's Office of Regional Economic Integration.

Conclusion

LCY bond markets in emerging East Asia have come a long way since the 1997/98 Asian crisis. During the recent global financial crisis, these markets emerged as a key source of funding for government stimulus policies and domestic companies. Yet, the Lehman shock in 2008 and the ongoing eurozone debt crisis have tested the resilience of these markets, and the threat of financial contagion is real. A closer analysis shows that shock and volatility spillovers from both crises to Asian markets are quite significant.

While there are several direct and indirect implications of these spillovers, three issues stand out. First, persistence of volatility could reduce the attractiveness of this new asset class—as it directly impacts investor perception of the collateral value of LCY bonds. Second, any significant shock spillovers and spike in volatility leads to volatile capital outflows from local markets—with a direct impact on liquidity. The liquidity gap from the withdrawal of foreign funds is not immediately filled by domestic investors. Lastly, the spillovers and persistence of volatility could raise borrowing costs and lead the private sector to postpone using local markets for funding. All of these conditions can generate greater vulnerabilities.

From this perspective, even though the economies of emerging East Asia are doing relatively better than in other parts of the world, policymakers cannot be complacent. As far as challenges in the bond market are concerned, they need to take steps to improve liquidity by developing a stronger domestic investor base to make local markets more resilient and better able to support productive activities in the real sector. Yet, even with the right policies, volatile capital flows may not be preventable, especially when factors beyond domestic controls dominate. When this happens, the resulting vulnerabilities cannot be dealt with by relying on domestic safety nets alone; support from regional financial safety nets is needed as well. This is where regional cooperation needs to be strengthened.

Appendix

Volatility patterns of bond yield returns across different periods are first extracted by using AR(1) - GARCH (1, 1) process:

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \varepsilon_t$$

where y_t is the bond yield return. Variances obtained from the mean equation are then modeled as a GARCH process to generate the conditional variances. The GARCH equation is represented by

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2,$$

where σ_t^2 is the conditional variance of the time-series, and ε_t^2 are squared residuals. The square of past residuals (ε_{t-1}^2) refers to the AR term, and the lagged variances (σ_{t-1}^2) refer to the GARCH term.

To estimate the spillovers of shock sources on impacted markets, bivariate GARCH models are estimated. For the impact of the Lehman shock, the US Treasury market and US corporate bond market are used as the two main sources. For the eurozone debt crisis, perturbations in German Bunds, the EU Composite Bond Yield Index, and European corporate debt (mainly financial sector) are used to examine their fallout on emerging East Asia's debt markets. Three time periods are defined: (i) the pre-crisis from July 2005 to August 2008, (ii) the Lehman shock from September 2008 to March 2009, and (iii) the new peak of the crisis in Greece and the eurozone debt crisis from September 2011 to May 2012.

A vector autoregressive (VAR) process for week-on-week bond returns is initially estimated, given the serial correlation found in the returns time series. Results of the Schwarz information criterion are then used to determine the optimal lag-length for the VAR estimation. The conditional mean equation is represented as

$$R_t = \alpha + \sum_{k=1}^{P} \Phi_p R_{t-k} + \varepsilon_t$$

where R_t is an $Nx1$ vector of week-on-week returns for each of the benchmark local currency (LCY) bond yields, Φ_p is a matrix of parameters, and $(\varepsilon_t|\mathrm{I}_{t-1}) \sim (0, H_t)$ is an $Nx1$ vector of random errors or innovations for each LCY bond market at time t given past information I_{t-1} (Karolyi, 1995).

The diagonal elements of the matrix Φ_p measure own market-lagged impacts; while the off-diagonals capture the effect of lagged return in one market on the current movement in the specific market being observed (cross-mean spillovers).

The resulting residual vectors are modeled as multivariate GARCH, where the NxN conditional variance-covariance matrix H_t is estimated using the unrestricted version of the Baba-Engle-Kraft-Kroner (BEKK) model defined in Engle and Kroner (1995). The BEKK model has the attractive property that the conditional variance-covariance matrix is positive definite by construction. The model has the form

$$H_t = CC' + \sum_{j=1}^{q} \sum_{k=1}^{K} A_{kj}' \left(\varepsilon_{t-j} \varepsilon_{t-j}'\right) A_{kj} + \sum_{j=1}^{p} \sum_{k=1}^{K} B_{kj}' H_{t-j} B_{kj}$$

where A_{kj}, B_{kj}, and C are NxN parameter matrixes, and is lower triangular. The decomposition of the constant term into a product of two triangular matrixes is to ensure positive definiteness of H_t. The BEKK model is covariance stationary if and only if the eigenvalues of $\sum_{j=1}^{q} \sum_{k=1}^{K} A_{kj} \otimes A_{kj} + \sum_{j=1}^{p} \sum_{k=1}^{K} B_{kj} \otimes B_{kj}$, where $\otimes$ denotes the Kronecker product of two matrixes are less than one in modulus. The summation limit determines the generality of the process. Whenever $K > 1$, an identification problem arises because there are several parameterizations that yield the same representation of the model. Engle and Kroner (1995) give conditions for eliminating redundant, observationally equivalent representations.

With this specification, the conditional variances and covariances depend on the lagged values of all conditional variances and covariances across bond market returns, as well as the lagged squared errors and cross-products of error terms (Brooks 2008). In this specification, C is a matrix of c_{lm} constants, A_{kj} is a parameter matrix of a_{lm} elements, indicating the extent of market shock spillovers, and B_{kj} is a parameter matrix of b_{lm} elements, capturing the market volatility spillover between markets l and m.

Estimation of a BEKK model—via maximum likelihood (ML)—involves somewhat heavy computations due to several matrix inversions. The number of parameters, $(p+q)KN^2 + N(N+1)/2$, in the full BEKK model remains quite large. Obtaining convergence may therefore be difficult because log-likelihood is not linear in parameters. There is the advantage, however, that the structure automatically ensures positive definiteness of H_t, so this does not need to be imposed separately. Partly because numerical difficulties are so common in the estimation of BEKK models, it is typically assumed $p = q = K = 1$ in applications.[17]

Consider the bivariate first order $(K = 1)$ BEKK model

$$H_t = CC' + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B$$

Expanding this,

$$\begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,t} \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix}\begin{bmatrix} c_{11} & c_{21} \\ c_{12} & c_{22} \end{bmatrix}$$
$$+ \begin{bmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \end{bmatrix}\begin{bmatrix} \varepsilon_{1,t-1} \\ \varepsilon_{2,t-1} \end{bmatrix}[\varepsilon_{1,t-1} \quad \varepsilon_{2,t-1}]\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$
$$+ \begin{bmatrix} b_{11} & b_{21} \\ b_{12} & b_{22} \end{bmatrix}\begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{21,t-1} & h_{22,t-1} \end{bmatrix}\begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$$

where $h_{12,t} = h_{21,t} = h_{cov,t}$.

The representations of main diagonal elements of the conditional variance-covariance matrix H_t:

$$h_{11,t} = (c_{11}^2 + c_{12}^2)$$
$$+ \left(a_{11}^2\varepsilon_{1,t-1}^2 + 2a_{11}a_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{21}^2\varepsilon_{2,t-1}^2\right)$$
$$+ \left(b_{11}^2 h_{11,t-1} + 2b_{11}b_{21}h_{cov,t-1} + b_{21}^2 h_{22,t-1}\right)$$

$$h_{22,t} = (c_{21}^2 + c_{22}^2)$$
$$+ \left(a_{12}^2\varepsilon_{1,t-1}^2 + 2a_{12}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{22}^2\varepsilon_{2,t-1}^2\right)$$
$$+ \left(b_{12}^2 h_{11,t-1} + 2b_{12}b_{22}h_{cov,t-1} + b_{22}^2 h_{22,t-1}\right)$$

where $h_{11,t}$ and $h_{22,t}$ are the conditional variance equations of markets $l = 1$ and $m = 2$.

The parameters of interest in this study are the off-diagonal elements of A and B corresponding to the a_{lm} $(where\ l \neq m)$—indicating the extent of market shock spillovers—and b_{lm} $(where\ l \neq m)$ —capturing the volatility spillover between l and m.

[17] Most financial time series volatility clustering characteristics are aptly modeled by a GARCH(1,1) process ($p = q = 1$). This implies that conditional variances and covariances depend on one period lag values of all the conditional variances and covariances across bond market returns, as well as one period lag squared errors and cross-products of error terms. Setting $K = 1$ allows mathematical tractability of the model.